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16. ABSTRACT

Methods of determining mortar strength were investigated which would reduce testing time. These investigations resulted in a method of determining mortar strength after curing the test specimens for 24 hours. The compressive strength of the specimens after 24 hours cure is approximately the same as the 7 day cure test and the ranking of the sands remain the same. The procedure includes the use of a modified sand grading, constant water-cement ratio for the control mortar and the use of Type III cement with calcium chloride added. The reproducibility of the test is poor by either method but no significant loss is evident in the use of the 24 hour cure method. Concurrent testing by the two methods, 7 day and 24 hour cure, is recommended to insure consistency until new specifications, based on accelerated test results, can be developed. A statistical analysis was conducted to determine the variations and significance of the different methods.

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HIGHWAY RESEARCH REPORT

MORTAR STRENGTH OF PORTLAND CEMENT CONCRETE SANDS

71-24

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 635149

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration June, 1971

STATE OF CALIFORNIA—TRANSPORTATION AGENCY
RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

June 1971

Final Report M&R 635149
Subproject 39155
HPR F-4-13

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

MORTAR STRENGTH OF PORTLAND

CEMENT CONCRETE SANDS

Donald L. Spellman
Prinicipal Investigator

J. R. Stoker
Robert W. Ford
Co-Investigators

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Spellman, D. L., Stoker, J. R., and Ford, R. W. "Mortar Strength of Portland Cement Concrete Sands," State of California, Department of Public Works, Division of Highways, Materials and Research Department, May 1971. Project Work Order No. M&R 635149, Agreement No. F-4-13.

ABSTRACT: Methods of determining mortar strength were investigated which would reduce testing time. These investigations resulted in a method of determining mortar strength after curing the test specimens for 24 hours. The compressive strength of the specimens after 24 hours cure is approximately the same as the 7 day cure test and the ranking of the sands remain the same. The procedure includes the use of a modified sand grading, constant water-cement ratio for the control mortar and the use of Type III cement with calcium chloride added. The reproducibility of the test is poor by either method but no significant loss is evident in the use of the 24 hour cure method. Concurrent testing by the two methods, 7 day and 24 hour cure, is recommended to insure consistency until new specifications, based on accelerated test results, can be developed. A statistical analysis was conducted to determine the variations and significance of the different methods.

KEY WORDS: Accelerated testing, calcium chloride, cements, curing, mortars, test methods, sands.

ACKNOWLEDGEMENT

This project was performed in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Agreement No. F-4-13.

The opinions, findings, and conclusions expressed in this report are those of the authors and are not necessarily those held by the Federal Highway Administration.

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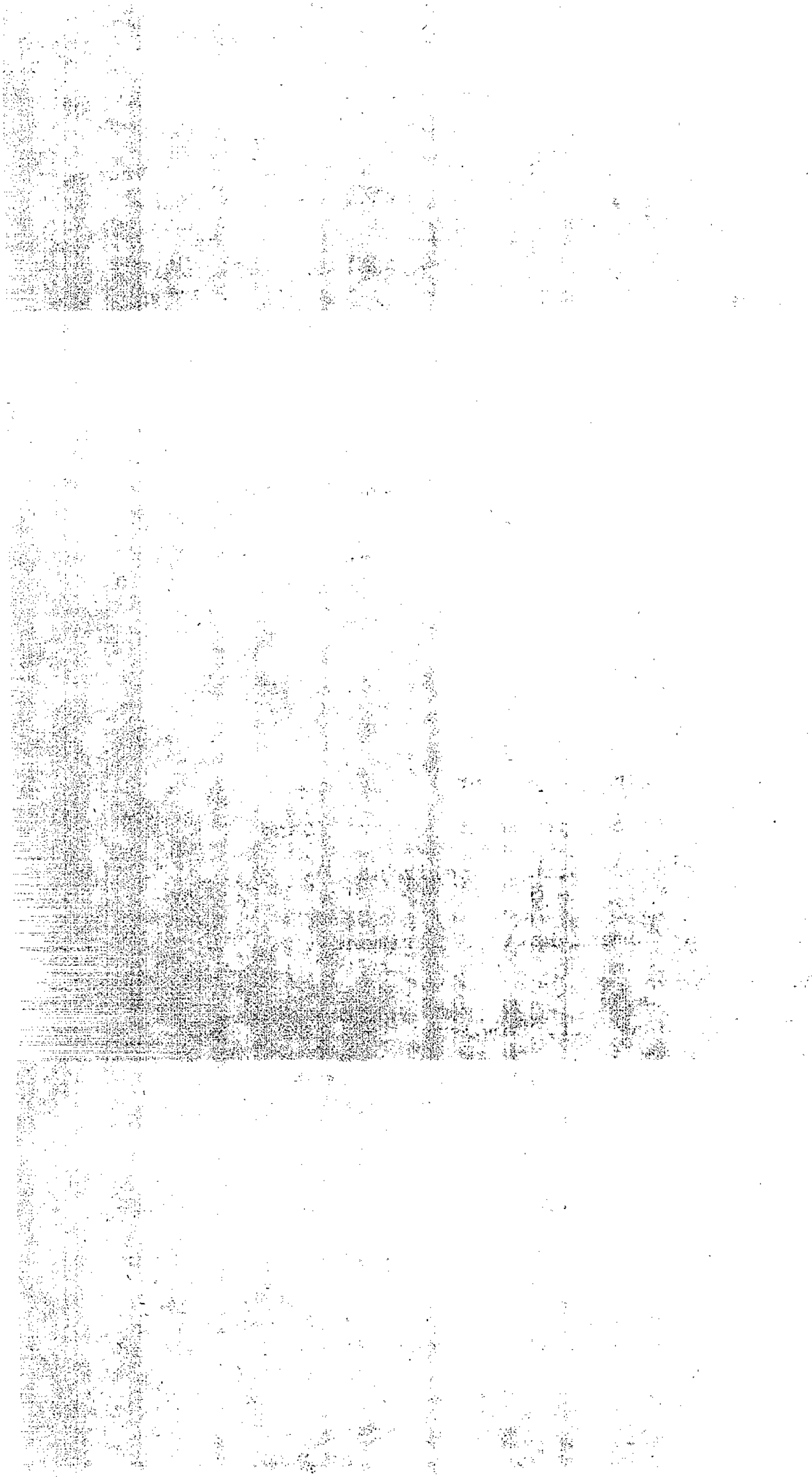

MORTAR STRENGTH OF PORTLAND CEMENT CONCRETE SANDS

INTRODUCTION AND BACKGROUND

Among the factors which influence the strength and durability of portland cement concrete, is the strength of the fine aggregate. The relative mortar strength test, Test Method No. Calif. 515, is used to measure strength of concrete sands in acceptance testing. The test not only measures the inherent strength of the sand, but also serves to detect the presence of deleterious coatings or other material which could have an adverse effect on mortar strength.

Since this test requires a week to perform, the need to repeat tests or to test new material sources during the course of a construction project may cause delays which are costly to the State and to the Contractor. The extended test time is primarily caused by the need to allow time for the cement to harden and cure. Therefore, ways were sought to shorten test time by accelerating the curing process.

Research performed under a State-financed project had established that:

1. Seven days required for curing test specimens could be reduced to 48 hours by curing at elevated temperatures.

2. Presoaking of the sands overnight reduced their mortar strength relative to Ottawa sand mortar.

3. Neither of the above modifications significantly reduced between batch variance of the relative mortar strength test results.

This project, performed in cooperation with the Federal Highway Administration, continues research started under that State financed project. The targeted objective of this project was to reduce the time required for the relative mortar strength test from seven days to one day, while maintaining adequate control over sand mortar strength relationships. This objective has partially been achieved.

This report covers a series of test phases conducted over a 4-year period. Each subsequent phase was designed to explore alternative procedures for producing improvement. Since the solution to the problem was not of high priority, the work was carried out in a relatively slow fashion. The solution proved more difficult than first imagined because test variables affected results to a much greater degree than anticipated, and this in turn required additional work to evaluate.

FINDINGS

Three major findings of this project are listed below. Other findings are included in the Discussion of Procedures and Analysis of Data sections.

1. The repeatability of Test Method No. Calif. 515 is poor. Most modifications of test conditions failed to significantly improve the test repeatability. Repeatability is also poor for control test mortars containing Ottawa sand.

2. The source and grading of the test sand, type of cement, and the flow of the wet mortar significantly affects the strength of test specimens.

3. By using Type III cement plus 2% by weight of calcium chloride, the seven day curing period required in Test Method No. Calif. 515 may be reduced to 24 hours. The ranking of sand and the test repeatability are not significantly affected by substituting the accelerated method for the existing method.

DISCUSSION OF PROCEDURES

In general, mortar testing followed procedures outlined in California Test Method 515, with modifications of conditions as desired at each phase of the project. In California Test Method 515, the water needed to attain saturated-surface-dry condition is added to sand 15 to 30 minutes prior to mixing the mortar. The mortar is hand-mixed. In an earlier State-financed project, overnight soaking and machine mixing were evaluated. While repeatability was only slightly improved, lower mortar strength resulted for the test sands. The Ottawa sand mortar, used as the control, was not affected to the same degree by the revised procedures. As a result, the relative strengths of the presoaked sands were lower. A relative strength of 95% is required for acceptance. Some sands that previously met 95% requirement failed to meet this requirement in the modified test. Rather than change the acceptable relative strength at that time, it was decided to utilize what was learned while exploring other factors.

The Federally-financed project consisted of four experimental phases. Analyses of Variance (ANOVA) were performed on the data from Phases II, III and IV.

In all phases of this project, sands were presoaked overnight in covered containers with water in excess of the amount needed to produce the saturated-surface-dry condition. All mortars were machine-mixed in accordance with ASTM C-305 except that a mixer was modified to permit mixing of test sands passing No. 4 sieve.

Phase I - Preliminary Experiment

The object of this phase was to accelerate the testing by use of Type III cement. Since the relative strength depends somewhat on the strength levels at which comparisons are made, one of the first tasks was to determine at what age mortar made with Type III cement had a compressive strength comparable to that made with Type II cement after 7 days moist curing. In general, it is believed that the strength of the paste in mortar should be of constant strength, but high enough to cause failure of the sand itself, or failure by virtue of weak paste-to-sand bond.

Type II cement mortars were tested after 7 days of moist curing; Type III cement mortars were tested after 1, 2, 4 and 8 days of moist curing. Each 1-day or 7-day test was a compressive strength test on three cubes from a single batch of mortar. The 2, 4 and 8-day tests were performed on one cube each from a batch of three. Two rounds were made for each test condition. Test results are shown in Table I and Figure 1.

The results indicated that (a) under identical curing conditions, mortars containing Type III cement required from 2 to 5 days to attain the same strength as that attained in 7 days using Type II cement mortars; (b) the sand having the higher relative mortar strength at age 7 days when Type II cement was used also had the higher relative mortar strength at 1, 2, 4 and 8 days when Type III cement was used, though not to the same degree. The sands tested had the same rankings relative to the control sand, at any curing period between 2 and 8 days; (c) microscopic examination of failed specimens revealed that the control sand and the round grains in test sands failed in bond to cement paste. Angular sand particles failed by fracturing indicating that strength levels were high enough to cause failure in the sand.

Phase II - Four Factor Experiment

The second and largest phase, was a factorial experiment. This was an extension of previous work (under the State-financed project) to evaluate the interrelated influences of selected test conditions on the compressive strengths of mortars containing the test sands. The experiment involved the following factors:

Factor	Levels
Source of Sand	Five sands from different sources having different physical strengths
Sand Grading	Two gradings were compared; the so-called "standard grading" called for in Test Method No. Calif. 515, and a somewhat finer grading typical of concrete sands being currently produced.*
Type of Cement	Types II and III (III is a high early strength type)
Flow of Mortar	Three levels 75 to 85, 95 to 105, and 115 to 125 (a measure of mortar wetness-higher flows are wetter).

The Type II cement mortars were cured 7 days, while the Type III cement mortars were cured one day.**

Two rounds of tests were performed for each possible combination of factors (a total of 120 tests). Compressive strength testing of three cubes made from a single batch of mortar comprised a test. Scheduling of tests was randomized.

Test results from this phase, found in Tables II, a-e, and III, indicate that:

1. All the factors evaluated influence mortar strengths of concrete sands and are more significant than testing error.

2. With some exceptions, the several testing conditions rank the sands in the same order as the routine method. Other sands would not necessarily be ranked in a similar order by the test procedure described.

3. The repeatability of strength results for all five sands appears to be best when Type III cement, special grading, and 115 to 125 flow are used. The strength of the cement paste under these conditions, however, is considered to be too low to test the strength of the sands.

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*The special grading was proposed as a modification to Test Method No. Calif. 515, because the presently specified grading often requires large quantities of sand in order to obtain sufficient 4x8 sieve size material for the test. Many sands now being produced for concrete have comparatively little No. 4x8 material as compared to sand furnished 10-15 years ago. The limitation on passing No. 50 was intended to reduce variability in water demand caused by between-batch fluctuations of the fines content. The standard and special gradings were as follows:

Sieve No.	Percent Passing	
	Standard	Special
4	100	100
8	78	--
16	59	60
30	35	35
50	--	15

**One-day and seven-day tests permit greater flexibility in scheduling during a 5-day work week than 2, 3, or 4-day tests. Since the ranking of the three sands tested in the Phase II was the same regardless of cement type or curing time, the one-day curing period appeared to be a reasonable choice for mortars containing Type III cement.

Phase III - Calcium Chloride Experiment

In the four factor experiment, (Phase II), the test results for Type III cement mortars cured for one day did not correlate well with those obtained for Type II mortars cured for 7 days (generally too low). Under some test conditions the accelerated tests ranked the sands in the same order as Test Method No. Calif. 515; with others it did not. In Phase III, calcium chloride was used to increase the strengths of one-day tests in an effort to produce better correlation with the 7-day strengths.

Calcium chloride was added in the amount of 2% by weight of Type III cement. This salt, dissolved,in a portion of the mix water, was added to the mortar during mixing. Ottawa control sand and the five sands which had been used in the factorial experiment were included in these tests. Three rounds of tests were performed with each cement and sand combination; however, due to an apparent mixup of Round 3 specimens, results for that round are are not considered here.

Table IV, a-f inclusive, show the data obtained which is plotted in Figures 2, 3 and 4.

The results of this phase confirm that:

1. Type III cement plus 2% calcium chloride may be used in lieu of Type II cement to accelerate relative mortar strength tests, in a 24-hour test. In fact this combination increased the spread of sand strengths, reflecting increased sensitivity to sand strength variations.

2. The five test sands are ranked in the same order with Type III cement and 2% calcium chloride, cured for 24 hours, as they were with Type II cement mortars cured for 7 days.

3. A definite problem exists with regard to repeatability of mortar strength tests. The variability of Ottawa sand mortar compressive strengths appears to be excessive for effective use as a control. The cause or causes of these variations should be determined in order to reduce the replicate testing necessary to obtain a satisfactory confidence level in a test.

Phase IV - Constant Water/Cement Ratio Experiment

The earlier phases of this project indicated a need to improve the repeatability of Test Method No. Calif. 515. Experiments in which certain test conditions were varied generally failed to produce appreciable improvement. Much of the difficulty lies with the poor repeatability of compressive strength results for the control sand. Tables II and III suggest that an accelerated test, with good repeatability, could be developed if a suitable control (for evaluating the influence of the cement on the mortar strengths) were found.

After this project was initiated, ASTM Committee C-1 studied and adopted a fixed water-cement ratio in lieu of limits on flow in order to reduce between-laboratory variance on test results for method C-109, a mortar test for measuring the compressive strength of portland cement.

Phase IV was intended to determine whether using a constant water-cement ratio could be expected to reduce between-batch variance in the mortar strength of a concrete sand. Ottawa control sand and one concrete sand (No. 5), which had been tested many times previously, were used. The quantity of sand used for each test was determined in accordance with Test Method No. Calif. 515. The flow was measured for each condition on the first round only.

Five rounds of tests were performed at two water-cement ratios for each of the two sands. A water-cement ratio of 0.4 was used to obtain the approximate consistency of mortar required in Test Method No. Calif. 515. ASTM Designation C-87-58T (a test for relative mortar strength which was abandoned), required a constant water-cement ratio of 0.6. This ratio was included in the constant water-cement ratio experiment to determine which mix design would give better repeatability of test results.

The 0.6 water-cement ratio resulted in mortars that were too fluid when the relative proportions of sand and cement were as specified in Test Method No. Calif. 515. To overcome this problem, the amounts of cement and water used were reduced from 400 gms and 250 ml to 250 gms and 150 ml respectively. Since this mixture produced mortar having lowered strength, an additional series of mortars was made from the control sand having 250 gms of cement and 100 ml of water for determining the influence of reduced cement content on mortar strengths. Curing conditions were as specified in Test Method No. Calif. 515 (7 days moist curing). Table V shows the data from the fixed water-cement ratio experiment.

Use of a fixed water-cement ratio did not improve the repeatability of the test. The results indicate that increasing the water-cement ratio will not eliminate the variations observed.

Increasing the water-cement ratio reduced the relative mortar strength of test sand No. 5.

Increasing the W/C ratio from 0.4 to 0.6 decreased strengths by about one-half or more. The lower strength limits may have an adverse affect on how failure occurs. As stated previously, it is desirable to have the sand strength the determining factor in failure, otherwise one sand would look as good as another since failure would always be through the weaker cement-water paste.

ANALYSIS OF DATA

Analyses were made on the full factorial experiments conducted during Phases II, III and IV of this project. Model equations and analysis of variance (ANOVA) tables are shown in Tables VI, VIIa, VIIb and VIII.

The analyses showed that:

1. In all three experiments, poor test reproducibility was indicated by the significant differences in average compressive strengths obtained from the duplicate batches of mortar. Based on the analysis of the Phase III experiment, one can expect that the mean compressive strength of 10% of the batches run will be in error in excess of 11% of the "real" mean compressive strength.

2. In the Phase II experiment, the compressive strengths obtained from cubes fabricated using the special grading were significantly lower than the strengths obtained when the standard grading was used. (A subsequent analysis using only that data from mortar fabricated using Type III cement, failed to indicate any significant difference in test reproducibility by use of either of the two gradings.)

3. In the Phase II experiment, with sand of standard grading, the differences in mean compressive strength between batches of mortar in the 115 to 125 flow range made from Type II cement were significantly greater than between batches in the 75-85 and 95-105 flow ranges. The data failed to indicate a significant difference in "between batch" precision between the 75-85 and 95-105 flow ranges of mortar. The lowest between-batch variance was observed with mortars containing Type III cement, special grading sand and 115-125 flows. This condition also produced the lowest strengths.

4. The data from the Phase III experiment fails to indicate any significant difference in the compressive strengths obtained on a given sand when the mortar was fabricated using either Type II cement, or Type III cement with calcium chloride, under the curing conditions set for each cement. The analysis did not indicate any significant change in the relative quality or rank of the sands between the use of the two cements.

5. The test data from Phase III tests failed to indicate any significant difference in test repeatability by use of either of the two cements.

6. The test data from Phase IV tests failed to indicate any significant difference in test repeatability induced by using either the 0.4 w/c ratio or the 0.6 w/c ratio.

CONCLUSIONS

1. Based on the above analyses, it appears that mortars fabricated using Type III cement with calcium chloride and cured for 24 hours will have essentially the same compressive strengths for a given sand as mortars fabricated using Type II cement after a seven-day moist curing period.

2. The relative compressive strengths of test sands should not be significantly different by either of the two methods.

3. The repeatability or precision of this test, which is very poor, should not be significantly different between the two methods.

4. The above conclusions are based on the Phase III experiment where a 75-85 flow range was used. If the 115-125 flow range were used, significantly lower strengths and poorer test repeatability would result.

5. Results of the Phase II experiment, which did not include the control sand, indicated that significantly lower strengths will be obtained using the special grading. There is no indication that either the relative quality (rank) or test reproducibility would be significantly affected by a change in sand grading alone.

6. There is no indication that using a constant water/cement ratio in lieu of the present flow range would improve the test reproducibility.

RECOMMENDATIONS

1. In addition to Test Method No. Calif. 515-D it is recommended that an accelerated mortar strength test be used in testing routine samples of concrete sands. The modified procedure involves overnight soaking of all sands, a special (finer) grading of test sand, constant water/cement ratio in the control sand mortar, Type III cement plus 2% calcium chloride, and a 24 hour period of moist curing. The purpose of the parallel testing is to examine the degree of correlation between results obtained by the two methods when sands from a large number of sources are tested.*

2. If the new test method appears to be satisfactory, it is recommended that the specifications for concrete sand be revised, if necessary, to permit continued acceptance under accelerated testing of sands which are now acceptable.

3. It is recommended that efforts be continued to identify sources of variance and improve the repeatability of the test.

*Implementation of this recommendation preceded publication of this report.

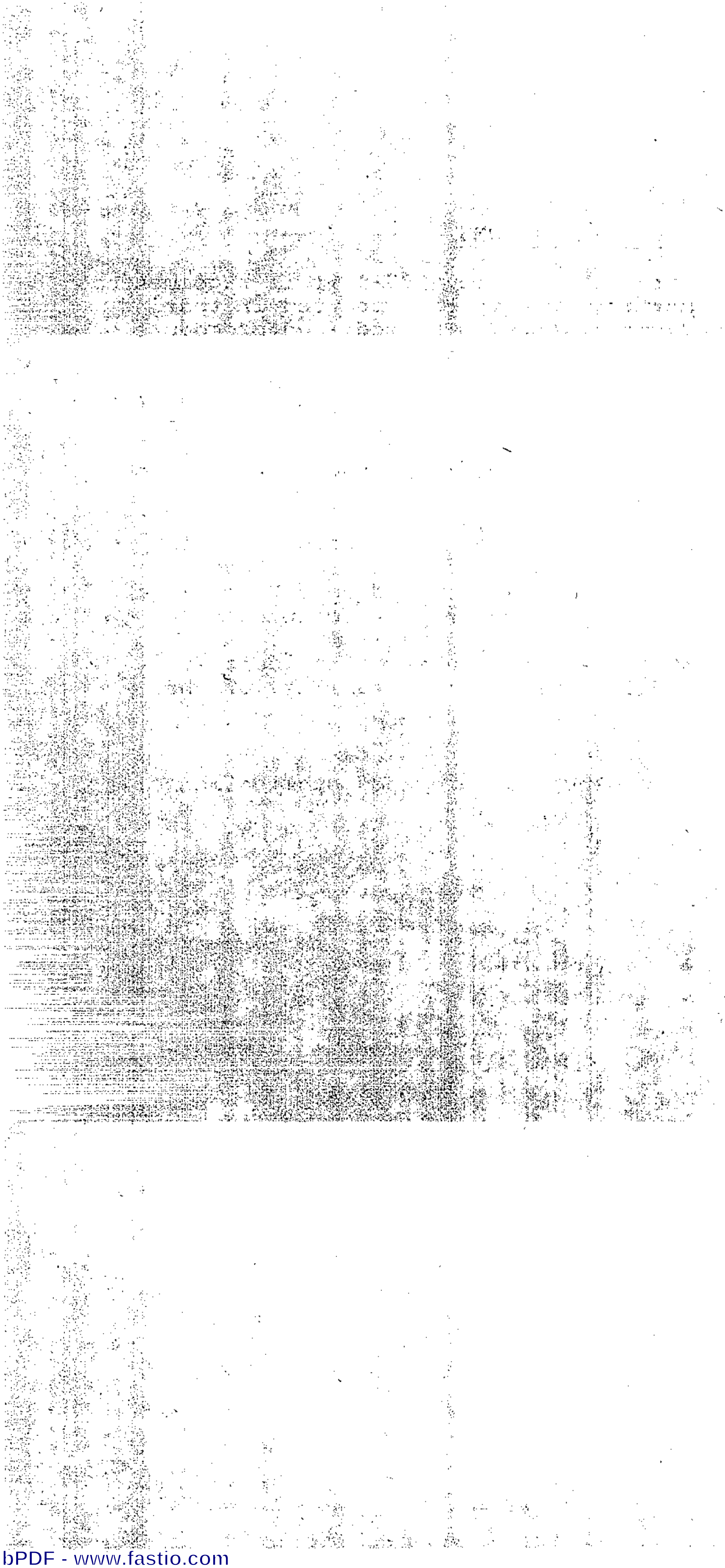


TABLE I

PHASE I

PRELIMINARY EXPERIMENT

	Type II Cement, 7 Days Moist-Cure		Type III Cement, Moist Curing 1 Day		2 Days		4 Days		8 Days	
Control Sand (Ottawa)										
Round	1	2	1	2	1	2	1	2	1	2
ml. Water	144	141	152	155	152	152	152	152	152	152
W/C	.360	.352	.380	.388	.380	.380	.380	.380	.380	.380
Flow	85	82-1/2	75	78	80	75	80	75	80	75
Lbs. Total Load on Each Cube	29200	30800	19900	18200	26900	28250	38350	37200	42550	42400
	28600	30350	19950	17850						
	29100	30150	19200	18100						
Compressive Strength, psi	7240	7610	4920	4510	6720	7060	9590	9300	10640	10600
Avg of 2 Rounds	7402		4720		6890		9440		10620	
Relative Mortar[a] Strength	100	100	100	100	100	100	100	100	100	100
Sand No. 1										
Round	1	2	1	2	1	2	1	2	1	2
ml. Water	180	183	196	204	195	196	195	196	195	196
W/C	.450	.458	.490	.51	.488	.490	.488	.490	.488	.490
Flow	82	82-1/2	77	82	81	77-1/2	81	77-1/2	81	77-1/2
Lbs. Total load on each cube	25200	24850	13700	12500	20700	19400	27750	27350	33850	32100
	24300	24100	13150	12600						
	25150	23450	13150	12210						
Compressive Strength, psi	6220	6030	3330	3110	5180	4850	6940	6840	8460	8020
Avg of 2 Rounds	6120		3220		5020		6890		8240	
Relative Mortar[b] Strength	85.9	79.2	67.7	69.0	77.1	68.7	72.4	73.5	79.5	75.7
Average Relative Mortar Strength	82.5		68.4		72.9		73.0		77.6	
Sand No. 4										
Round	1	2	1	2	1	2	1	2	1	2
ml. Water	154	156	175	175	172	175	172	175	172	175
W/C	.385	.390	.438	.438	.430	.438	.430	.438	.430	.438
Flow	77	81-1/2	80	75	83-1/2	85	83-1/2	85	83-1/2	85
Lbs. total load on each cube	35800	35700	17000	17000	29250	27400	37650	36000	43250	44750
	36500	34500	17600	17100						
	36550	35250	17500	16650						
Compressive Strength, psi	9070	8790	4340	4230	7310	6850	9410	9000	10810	11190
Avg of 2 Rounds	8930		4280		7080		9200		11000	
Relative Mortar[a] Strength	125.3	115.5	88.2	93.8	108.8	97.0	98.1	96.8	101.6	105.6
Average Relative Mortar Strength	120.4		91.0		102.9		97.4		103.6	

[a] By definition, the control sand has a relative mortar strength of 100
[b] Based on control using same cement and curing time

TABLE IIa

PHASE II

4-FACTOR EXPERIMENT

Sand No. 1

	Type II Cement, Moist-Cured for 7 Days						Type III Cement, Moist-Cured for 24 Hrs.					
Flow Range	75-85		95-105		115-125		75-85		95-105		115-125	
Round	1	2	1	2	1	2	1	2	1	2	1	2
Standard Grading:												
ml. water	177	177	185	185	210	206	192	194	208	208	233	235
W/C	.442	.442	.462	.462	.525	.515	.480	.485	.520	.520	.582	.588
Flow	81	82	97	95	125	122	75	80	98	98	116	121
Lbs. Total Load On Each Cube	24,800	24,850	21,550	23,250	16,800	17,500	12,860	12,700	10,600	11,120	7,240	6,260
	25,700	24,650	22,000	22,750	17,100	17,300	13,000	12,920	10,480	10,560	7,240	7,540
	24,400	24,400	22,100	23,300	17,700	18,000	12,720	12,900	10,440	10,920	7,240	7,980
Compressive Strength, psi	6240	6160	5470	5780	4300	4400	3220	3210	2630	2720	1810	1820
Special Grading:												
ml. Water	180	179	192	192	214	211	201	202	210	212	230	233
W/C	.450	.448	.480	.480	.535	.528	.502	.505	.525	.530	.575	.582
Flow	83	76	100	103	125	124	78	85	96	95	115	118
Lbs. Total Load On Each Cube	23,850	23,050	21,000	21,500	17,000	17,550	11,500	10,820	10,300	9,260	7,920	8,060
	23,750	23,500	21,150	21,400	16,550	16,700	11,000	11,600	10,530	9,320	7,800	7,820
	23,850	23,250	20,950	22,000	16,600	17,000	11,800	11,680	10,580	9,600	7,960	7,740
Compressive Strength, psi	5950	5820	5260	5410	4180	4270	2860	2840	2620	2350	1970	1970

TABLE IIb

PHASE II

4-FACTOR EXPERIMENT

Sand No. 2

	Type II, Cement, Moist-Cured 7 Days						Type III Cement, Moist-Cured 24 Hrs.					
Flow Range	75-85		95-105		115-125		75-85		95-105		115-125	
Round	1	2	1	2	1	2	1	2	1	2	1	2
Standard Grading:												
ml. Water	162	159	173	170	185	185	177	177	192	190	206	208
W/C	.405	.398	.432	.425	.462	.462	.442	.442	.480	.475	.515	.520
Flow	85	81	105	105	119	121	80	80	103	99	116	115-1/2
Lbs. Total	29,350	29,950	27,100	26,300	23,600	24,300	15,320	15,800	12,320	12,820	10,600	10,850
Load On	29,250	30,050	26,800	26,300	23,100	24,700	15,600	15,640	12,950	13,000	10,620	10,800
Each Cube	29,250	30,020	26,500	25,650	23,900	24,450	15,260	15,960	13,270	13,100	10,680	10,570
Compressive Strength, psi	7320	7500	6700	6520	5880	6120	3850	3950	3210	3240	2660	2680
Special Grading:												
ml. Water	164	162	170	169	186	186	181	179	192	194	219	219
W/C	.410	.405	.425	.422	.465	.465	.452	.448	.480	.485	.548	.548
Flow	83	82	103	98	120	122	85	76	97	102	123	122
Lbs. Total	27,700	28,150	26,000	27,100	21,400	21,800	15,160	15,480	13,270	12,700	9,260	8,940
Load On	27,000	28,250	26,100	27,050	21,550	21,850	15,120	15,920	13,400	12,520	9,200	8,960
Each Cube	27,450	28,650	25,950	26,950	22,200	22,050	15,100	15,260	13,200	12,120	9,000	9,260
Compressive Strength, psi	6850	7090	6500	6760	5430	5480	3780	3890	3320	3110	2290	2260

TABLE IIc

PHASE II

4-FACTOR EXPERIMENT

Sand No. 3

	Type II Cement, Moist-Cured 7 Days						Type III Cement, Moist-Cured for 24 Hrs.					
Flow Range	75-85		95-105		115-125		75-85		95-105		115-125	
Round	1	2	1	2	1	2	1	2	1	2	1	2
Standard Grading:												
ml. Water	161	161	170	170	188	188	179	179	202	199	209	215
W/C	.402	.402	.425	.425	.470	.470	.448	.448	.505	.498	.522	.538
Flow	81	79	98	98	120	120	79	76	105	100	112	113
Lbs. Total Load On Each Cube	29,350	28,100	26,100	26,250	20,700	22,350	13,840	15,400	10,200	11,160	10,000	8,860
	28,900	29,550	26,450	26,750	20,600	21,850	13,960	15,220	10,000	11,120	9,940	8,880
	29,800	28,750	25,950	25,800	20,900	21,500	14,220	16,340	10,000	10,900	9,880	8,880
Compressive Strength, psi	7340	7200	6540	6570	5180	5480	3500	3910	2520	2760	2480	2220
Special Grading:												
ml. Water	165	165	174	174	193	192	183	185	200	200	215	219
W/C	.412	.412	.435	.435	.482	.480	.458	.462	.500	.500	.538	.548
Flow	80	80	100	101	122	120	77	80	101	99	115	112
Lbs. Total Load On Each Cube	28,300	29,000	24,350	24,900	20,400	20,500	14,500	13,600	10,920	10,760	8,260	8,520
	27,750	28,900	24,650	24,750	20,500	20,100	14,320	13,160	11,180	10,780	8,380	8,580
	27,900	29,150	24,750	24,850	20,350	20,250	13,900	13,160	11,320	10,660	8,600	8,420
Compressive Strength, psi	7000	7250	6140	6210	5100	5070	3560	3330	2780	2680	2100	2130

TABLE IId

PHASE II

4-FACTOR EXPERIMENT

Sand No. 4

	Type II, Cement, Moist-Cured 7 Days						Type III Cement, Moist-Cured 24 Hrs.					
Flow Range	75-85		95-105		115-125		75-85		95-105		115-125	
Round	1	2	1	2	1	2	1	2	1	2	1	2
Standard Grading:												
ml. Water	156	154	167	167	184	184	176	176	195	192	210	213
W/C	.390	.385	.418	.418	.460	.460	.440	.440	.488	.480	.525	.532
Flow	85	81	102	96	119	123	80	84	105	103	114-1/2	116
Lbs. Total	33,600	35,700	30,500	32,600	24,050	25,000	17,220	16,620	13,220	12,700	10,000	10,100
Load On	33,650	36,150	29,100	33,100	23,950	25,900	16,620	16,920	13,060	12,620	10,060	10,040
Each Cube	34,600	33,750	30,650	32,000	24,100	25,900	16,380	16,820	13,000	12,700	10,030	10,290
Compressive Strength, psi	8490	8800	7520	8140	6010	6400	4180	4200	3270	3170	2510	2540
Special Grading:												
ml. Water	157	155	172	170	194	188	183	181	188	191	217	219
W/C	.392	.388	.430	.425	.485	.470	.458	.453	.470	.478	.542	.548
Flow	83	75	104-1/2	103	128	121	85	84	95	100	117	120
Lbs. Total	32,650	35,000	28,350	29,050	23,050	22,950	15,650	16,400	13,360	12,320	10,050	9,860
Load On	33,000	33,500	28,200	28,750	22,900	22,650	15,600	16,320	13,980	13,500	9,610	9,800
Each Cube	32,800	35,400	28,150	28,200	22,850	23,000	15,590	16,400	13,600	13,480	9,800	9,680
Compressive Stength, psi	8200	8660	7060	7170	5730	5720	3900	4090	3410	3280	2460	2440

TABLE IIe

PHASE II

4-FACTOR EXPERIMENT

Sand No. 5

	Type II Cement, Moist-Cured 7 Days						Type III Cement, Moist-Cured 24 Hrs.					
Flow Range	75-85		95-105		115-125		75-85		95-105		115-125	
Round	1	2	1	2	1	2	1	2	1	2	1	2
Standard Grading:												
ml. Water	158	157	166	166	187	185	175	178	191	191	207	213
W/C	.395	.392	.415	.415	.468	.462	.438	.445	.478	.478	.518	.532
Flow	83	84	100	100	122	124	75	80	100	100	115-1/2	120
Lbs. Total Load On Each Cube	32,000	32,000	29,550	28,800	23,450	22,800	17,000	15,700	12,060	12,720	11,000	9,440
	32,200	33,100	29,350	28,100	23,150	23,100	16,500	15,680	12,060	12,700	11,090	9,500
	31,850	32,150	29,900	28,150	22,700	22,750	17,270	15,920	12,460	12,320	11,080	9,460
Compressive Strength, psi	8000	8100	7400	7090	5780	5720	4230	3940	3050	3140	2760	2370
Special Grading:												
ml. Water	163	164	170	170	187	187	181	181	194	195	213	213
W/C	.408	.410	.425	.425	.468	.468	.452	.452	.485	.488	.532	.532
Flow	77	85	99	101	120	123	80	78	97	98	118	117
Lbs. Total Load On Each Cube	29,150	27,900	25,500	26,850	22,500	23,150	15,800	14,340	12,480	12,060	9,500	9,200
	30,550	27,950	27,000	26,250	22,450	23,000	15,200	14,800	11,980	11,480	9,200	9,240
	30,000	27,250	27,300	26,050	22,100	22,900	15,380	14,340	12,380	11,340	9,400	9,400
Compressive Strength, psi	7480	6920	6650	6600	5590	5750	3860	3620	3070	2910	2340	2320

TABLE III

PHASE II

4-FACTOR EXPERIMENT (SUMMARY)

Sand No.	1		2		3		4		5	
Type Cement	II	III	II	III	II	III	II	III	II	III
Days Moist Cured	7	1	7	1	7	1	7	1	7	1
	Average Compressive Strength psi									
Standard Grading										
Flow Range:										
75-85	6200	3215	7410	3900	7270	3705	8645	4190	8050	4085
95-105	5625	2675	6610	3225	6555	2640	7830	3220	7245	3095
115-125	4350	1815	6000	2670	5330	2350	6205	2525	5750	2565
Special Grading										
Flow Range:										
75-85	5885	2850	6970	3835	7125	3445	8430	3995	7200	3740
95-105	5335	2485	6630	3215	6175	2730	7115	3345	6625	2990
115-125	4225	1970	5455	2275	5085	2115	5725	2450	5680	2330

TABLE IVa

PHASE III

CALCIUM CHLORIDE EXPERIMENT

Control Sand

	Type II Cement, Moist Cured for 7 Days			Type III Cement + 2% $CaCl_2$ Moist Cured for 24 Hours		
Round	1	2	Avg. of 2 Rounds	1	2	Avg. of 2 Rounds
Ml Water	135	135		135	133	
W/C Ratio	.3375	.3375		.3375	.3325	
Flow	82	84		81	83	
Lbs. total load on each cube	32700 31150 32400	30800 28500 27850		27600 30100 26650	33100 32300 32400	
Compressive Stength, psi	8020	7260	7640	7030	8150	7590
Relative Mortar Strength*	100	100	100	100	100	100

*Used for comparison to succeeding batches of Test Sands.

TABLE IVb

PHASE III

CALCIUM CHLORIDE EXPERIMENT

Sand No. 1

	Type II Cement, Moist Cured for 7 Days			Type III Cement + 2% $CaCl_2$ Moist Cured for 24 Hours		
Round	1	2	Avg. of 2 Rounds	1	2	Avg. of 2 Rounds
Ml Water	157	155		161	157	
W/C Ratio	.3925	.3875		.4025	.3925	
Flow	77	77		81	76	
Lbs. total load on each cube	27550 27250 27250	27500 26700 27000		22600 21350 22350	25150 24500 23100	
Compressive Stength, psi	6840	6770	6805	5520	6060	5790
Relative Mortar Strength*	85	93	89	79	74	77

*Compared to control sand mixes Table IVa.

TABLE IVc

PHASE III

CALCIUM CHLORIDE EXPERIMENT

Sand No. 2

	Type II Cement, Moist Cured for 7 Days			Type III Cement + 2% $CaCl_2$ Moist Cured for 24 Hours		
Round	1	2	Avg. of 2 Rounds	1	2	Avg. of 2 Rounds
Ml Water	155	152		160	163	
W/C Ratio	.3875	.3800		.4000	.4075	
Flow	77	77		78	78	
Lbs. total load on each cube	30350 29400 29490	28850 29900 29100		28900 29000 28950	28200 27600 28800	
Compressive Stength, psi	7430	7320	7375	7240	7050	7145
Relative Mortar Strength	93	101	97	103	86	94

TABLE IVd

PHASE III

CALCIUM CHLORIDE EXPERIMENT

Sand No. 3

	Type II Cement, Moist Cured for 7 Days			Type III Cement + 2% $CaCl_2$ Moist Cured for 24 Hours		
Round	1	2	Avg. of 2 Rounds	1	2	Avg. of 2 Rounds
Ml Water	134	132		141	142	
W/C Ratio	.3350	.3300		.3525	.3550	
Flow	85	80		83	85	
Lbs. total load on each cube	29850	30800		33600	30250	
	29250	31600		33500	31300	
	29450	31850		34450	30600	
Compressive Stength, psi	7380	7850	7615	8460	7680	8070
Relative Mortar Strength	92	108	100	120	94	106

TABLE IVe

PHASE III

CALCIUM CHLORIDE EXPERIMENT

Sand No. 4

	Type II Cement, Moist Cured for 7 Days			Type III Cement + 2% $CaCl_2$ Moist Cured for 24 Hours		
Round	1	2	Avg. of 2 Rounds	1	2	Avg. of 2 Rounds
Ml Water	130	128		141	143	
W/C Ratio	.3250	.3200		.3525	.3575	
Flow	84	83		80	80	
Lbs. total load on each cube	30800 29300 31600	36150 33750 35850		37150 36650 37800	34750 34900 35850	
Compressive Stength, psi	7640	8810	8225	9300	8790	9045
Relative Mortar Strength	95	121	108	132	108	119

TABLE IVf

PHASE III

CALCIUM CHLORIDE EXPERIMENT

Sand No. 5

	Type II Cement, Moist Cured for 7 Days			Type III Cement + 2% $CaCl_2$ Moist Cured for 24 Hours		
Round	1	2	Avg. of 2 Rounds	1	2	Avg. of 2 Rounds
Ml Water	137	127		138	135	
W/C Ratio	.3175	.3175		.3450	.3375	
Flow	85	82		75	85	
Lbs. total load on each cube	35400	33200		39000	31700	
	32450	32250		39950	32900	
	33150	33800		41300	33250	
Compressive Stength, psi	8420	8270	8345	10020	8150	9085
Relative Mortar Strength	105	114	109	142	100	120

Table V

Constant Water/Cement Ratio Experiment

	1			2			3			4			5			Average		
gm cement	400	250	250	400	250	250	400	250	250	400	250	250	400	250	250	400	250	250
ml water	160	100	150	160	100	150	160	100	150	160	100	150	160	100	150	160	100	150
W/C	0.4	0.4	0.6	0.4	0.4	0.6	0.4	0.4	0.6	0.4	0.4	0.6	0.4	0.4	0.6	0.4	0.4	0.6
Control Sand																		
Flow	118	dry	133	---	---	---	---	---	---	---	---	---	---	---	---			
Lbs. total load on each cube	29150 29750 32350	13700 15000 14400	12100 12050 12400	27150 29700 30100	14950 12950 15700	11400 11750 11750	26050 29250 28850	16000 15500 15750	12950 12650 12500	36800 32100 31400	15000 16400 16850	12600 12550 12500	31300 30800 31250	15150 15850 16050	12400 12200 12150			
Compressive strength, psi	7600	3590	3050	7250	3630	2910	7010	3940	3180	8360	4020	3180	7780	3920	3060	7600	3820	3080
Relative[a] mortar strength	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Sand No. 5																		
Flow	102		124	---		---	---		---	---		---	---		---			
Lbs. total load on each cube	32400 31900 34100		15700 15200 16700	32000 27900 30900		14700 14850 14600	35800 35900 36750		14250 14050 13750	36650 36600 35850		16600 15150 15700	32700 32100 32300		12850 13050 12700			
Compressive strength, psi	8200		3970	7570		3680	9040		3500	9090		3950	8090		3220	8400		3660
Relative[b] mortar strength	107.9		130.2	104.4		126.5	129.0		110.0	108.7		124.2	104.0		105.2	110.8		119.2

a. By definition the control sand has a relative mortar strength of 100.

b. Based on control using same weight of cement and W/C ratio.

TABLE VI

ANOVA for Phase II

$$X = S_e^R + G_d^F + GS_{de}^R + C_c^F + CS_{ce}^R + CG_{cde}^F + CGS_{cde}^R + F_b^F + FS_{be}^R +$$
$$FG_{bd}^F + FGS_{bde}^R + FC_{bc}^F + FCS_{bce}^R + FCG_{bcd}^R + FCGS_{bcde}^R + B_{a(bcde)}^R +$$
$$E_{f(abcde)}$$

2 R a	3 F b	2 F c	2 F d	5 R e	3 R f	SOURCE	DF	EMS
2	3	2	2	1	3	Se (Sand)	4	V(E)+3V(B)+72V(S)
2	3	2	0	5	3	G_d (Grade)	1	V(E)+3V(B)+36V(GS)+180V(G)
2	3	2	0	1	3	GS_{de}	4	V(E)+3V(B)+36V(GS)
2	3	0	2	5	3	C_c (Cement)	1	V(E)+3V(B)+36V(CS)+90V(C)
2	3	0	2	1	3	CS_{ce}	4	V(E)+3V(B)+36V(CS)
2	3	0	0	5	3	CG_{cd}	1	V(E)+3V(B)+18V(CGS)+90V(CG)
2	3	0	0	1	3	CGS_{cde}	4	V(E)+3V(B)+18V(CGS)
2	0	2	2	5	3	F_b (Flow)	2	V(E)+3V(B)+24V(FS)+120V(F)
2	0	2	2	1	3	FS_{be}	8	V(E)+3V(B)+24V(FS)
2	0	2	0	5	3	FS_{bd}	2	V(E)+3V(B)+12V(FGS)+60V(FG)
2	0	2	0	1	3	FGS_{bde}	8	V(E)+3V(B)+12V(FGS)
2	0	0	2	5	3	FC_{bc}	2	V(E)+3V(B)+12V(FCS)+60V(FC)
2	0	0	2	1	3	FCS_{bce}	8	V(E)+3V(B)+12V(FCS)
2	0	0	0	5	3	FCG_{bcd}	2	V(E)+3V(B)+6V(FCGS)+30V(FCG)
2	0	0	0	1	3	$FCGS_{bcde}$	8	V(E)+3V(B)+6V(FCGS)
1	1	1	1	1	3	$B_{a(bcde)}$	60	V(E)+3V(B)
1	1	1	1	1	1	$E_{f(abcde)}$	240	V(E)
						TOTAL	359	

TABLE VI
(continued)

SOURCE	SS	DF	MS	F-RATIO	$F_{.05}$
Sand	3.8858	4	.97145	276.75	2.52
Grading	.2290	1	.22902	61.49	7.71
G*S	.0149	4	.00372	1.06	2.52
Cement	54.1009	1	54.10090	2461.82	7.71
C*S	.0879	4	.02198	6.26	2.52
C*G	.0026	1	.00257	1.03	7.71
C*G*S	.0100	4	.00250	.71	2.52
Flow Ratio	9.2219	2	4.61096	331.68	4.46
F*S	.1112	8	.01390	3.96	2.10
F*G	.0142	2	.00710	.55	4.46
F*G*S	.1026	8	.01282	3.65	2.10
F*C	.4246	2	.21231	37.39	4.46
F*C*S	.0454	8	.00568	1.62	2.10
F*C*G	.0196	2	.00978	1.07	4.46
F*C*G*S	.0730	8	.00912	2.60	2.10
Batch	.2106	60	.00351	7.81	1.41
Residual	.1079	240	.00045		
TOTAL	68.6621	359	.19126		

TABLE VIIa

ANOVA for Phase III, Complete

CaCl Experiment

$$X = \mu + S_c^R + C_b^F + SC_{bc}^R + B_{a(bc)}^R + E_{d(abc)}$$

6 R c	2 R b	2 F a	3 R e	SOURCE	DF	EMS
1	2	2	3	S_c	5	V(E)+3V(B)+12V(S)
6	0	2	3	C_b	1	V(E)+3V(B)+6V(CS)+36V(C)
1	0	2	3	SC_{bc}	5	V(E)+3V(B)+6V(CS)
1	1	1	3	$B_{a(bc)}$	12	V(E)+3V(B)
1	1	1	1	$E_{d(abc)}$	48	V(E)
				TOTAL	71	

SOURCE	SS	DF	MS	F-RATIO	$F_{.05}$
Sands	873306	5	174661	11.50	3.11
Cements	000427	1	000427	.00	6.61
S*C	139221	5	027844	1.83	3.11
Batches	182210	12	015184	180.82	1.96
Residual	040309	48	000840		
TOTAL	1235474	71	074010		

TABLE VIIb

ANOVA for Phase III, by Type of Cement

$$X = \mu + S_b^R + B_{a(b)}^R + E_{c(ab)}$$

6 R a	2 R b	3 R c		DF	EMS
6	1	3	S_b	5	V(E)+3V(B)+18V(S)
1	1	3	$B_{a(b)}$	6	V(E)+3V(B)
1	1	1	$E_{c(ab)}$	24	V(E)
TOTAL				35	

$$F_B = \frac{2165}{871} = 2.49$$

TYPE II CEMENT

SOURCE	SS	DF	MS	F-RATIO	$F_{.05}$
Sand	.16489	5	.03298	3.42	4.39
Batch	.05225	6	.00871	10.21	2.51
Residual	.02048	24	.00085		
TOTAL	.23761	35	.00679		

TYPE III CEMENT w/CaCl

SOURCE	SS	DF	MS	F-RATIO	$F_{.05}$
Sand	.84745	5	.16949	7.83	4.39
Batch	.12992	6	.02165	26.27	2.51
Residual	.01979	24	.00082		
TOTAL	.99716	35	.02849		

TABLE VIII

ANOVA for Phase IV

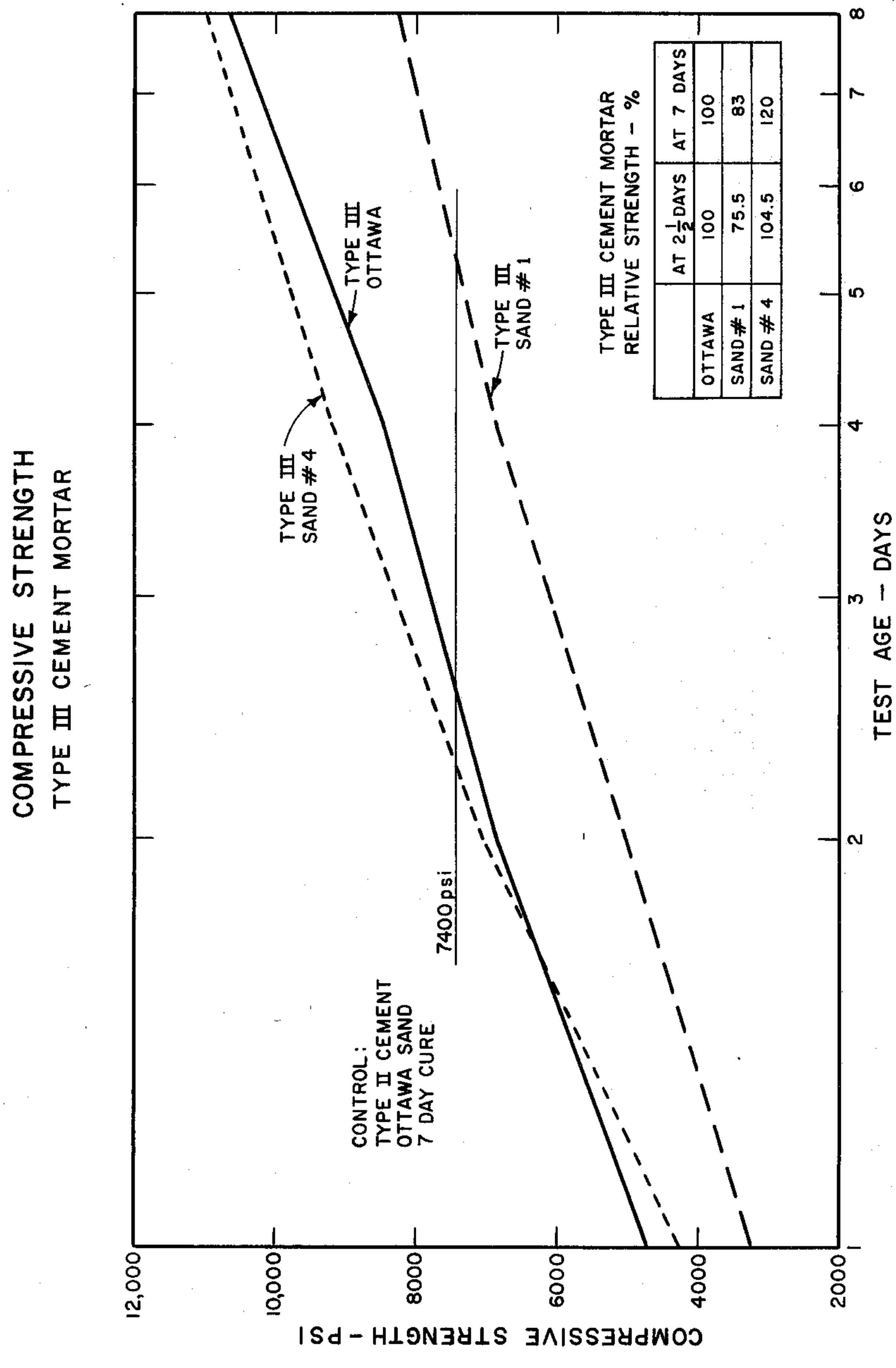
CONSTANT W/C RATIO EXPERIMENT

$$X = \mu + S_c^R + R_a^F + RS_{ac}^R + B_{b(ac)}^R + E_{d(abc)}$$

2 R c	2 F a	5 R b	3 R d	SOURCE	DF	EMS
1	2	5	3	S_c	1	V(E)+3V(B)+30V(S)
2	0	5	3	R_a	1	V(E)+3V(B)+15V(RS)+30V(R)
1	0	5	3	RS_{ac}	1	V(E)+3V(B)+15V(RS)
1	1	1	3	$B_{b(ac)}$	16	V(E)+3V(B)
1	1	1	1	$E_{d(abc)}$	40	V(E)
TOTAL					59	

SOURCE	SS	DF	MS	F-RATIO	$F_{.05}$
Sands	28420	1	28420	1935	4.49
Ratios	1129064	1	1129064	52595	161.0
S*R	02147	1	02147	146	4.49
Batches	23502	16	01469	963	1.90
Residual	06101	40	00153		
TOTAL	1189233	59	20156		

Figure 1



COMPRESSIVE STRENGTH
TYPE III CEMENT MORTAR
TYPE III OTTAWA
TYPE III SAND # 1
TYPE III SAND # 4
CONTROL: TYPE II CEMENT OTTAWA SAND 7 DAY CURE
7400 psi
TYPE III CEMENT MORTAR RELATIVE STRENGTH - %
AT 2½ DAYS
AT 7 DAYS
OTTAWA 100 100
SAND # 1 75.5 83
SAND # 4 104.5 120
COMPRESSIVE STRENGTH - PSI
2000
4000
6000
8000
10,000
12,000
TEST AGE - DAYS
1
2
3
4
5
6
7
8

Figure 2

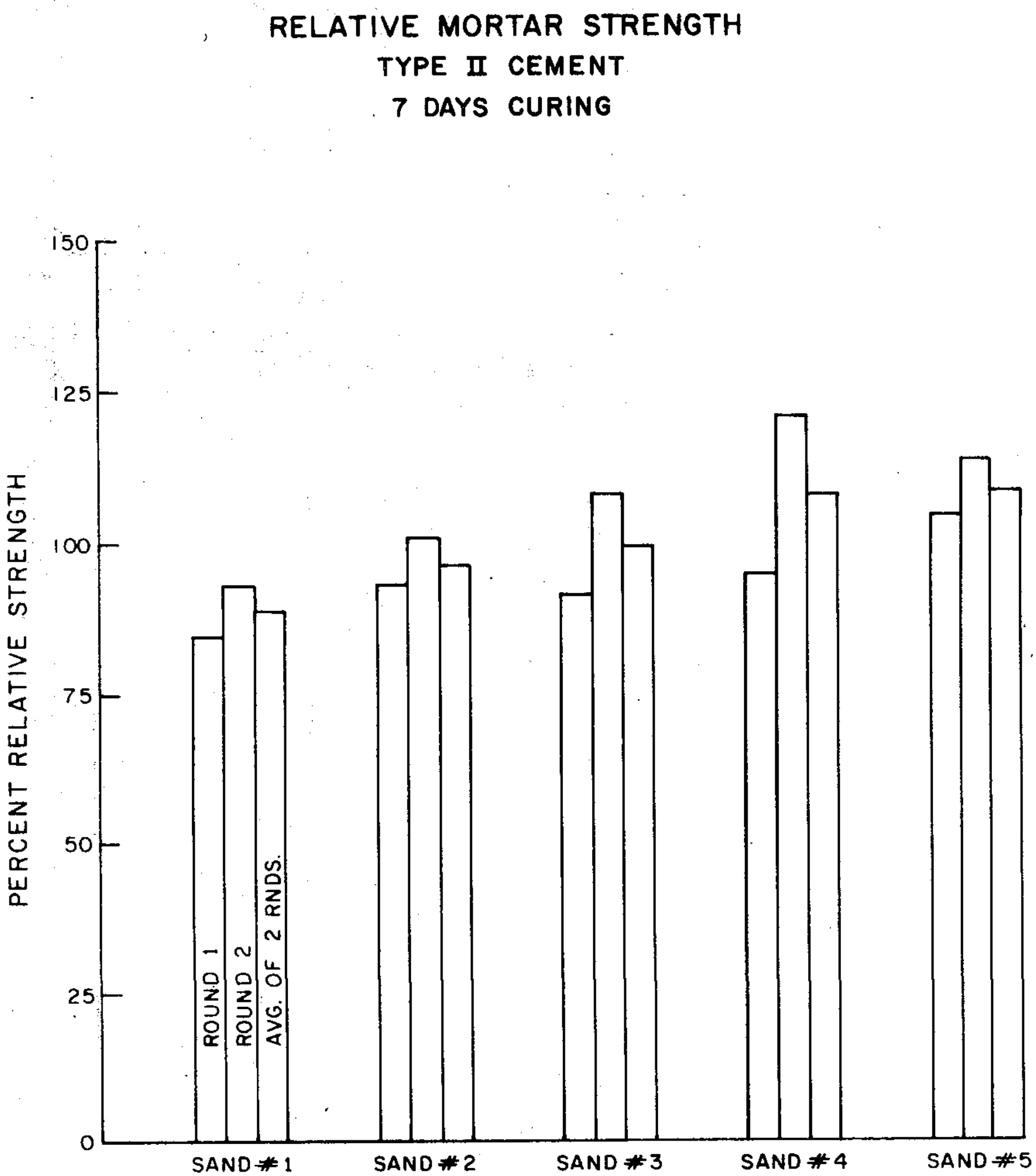
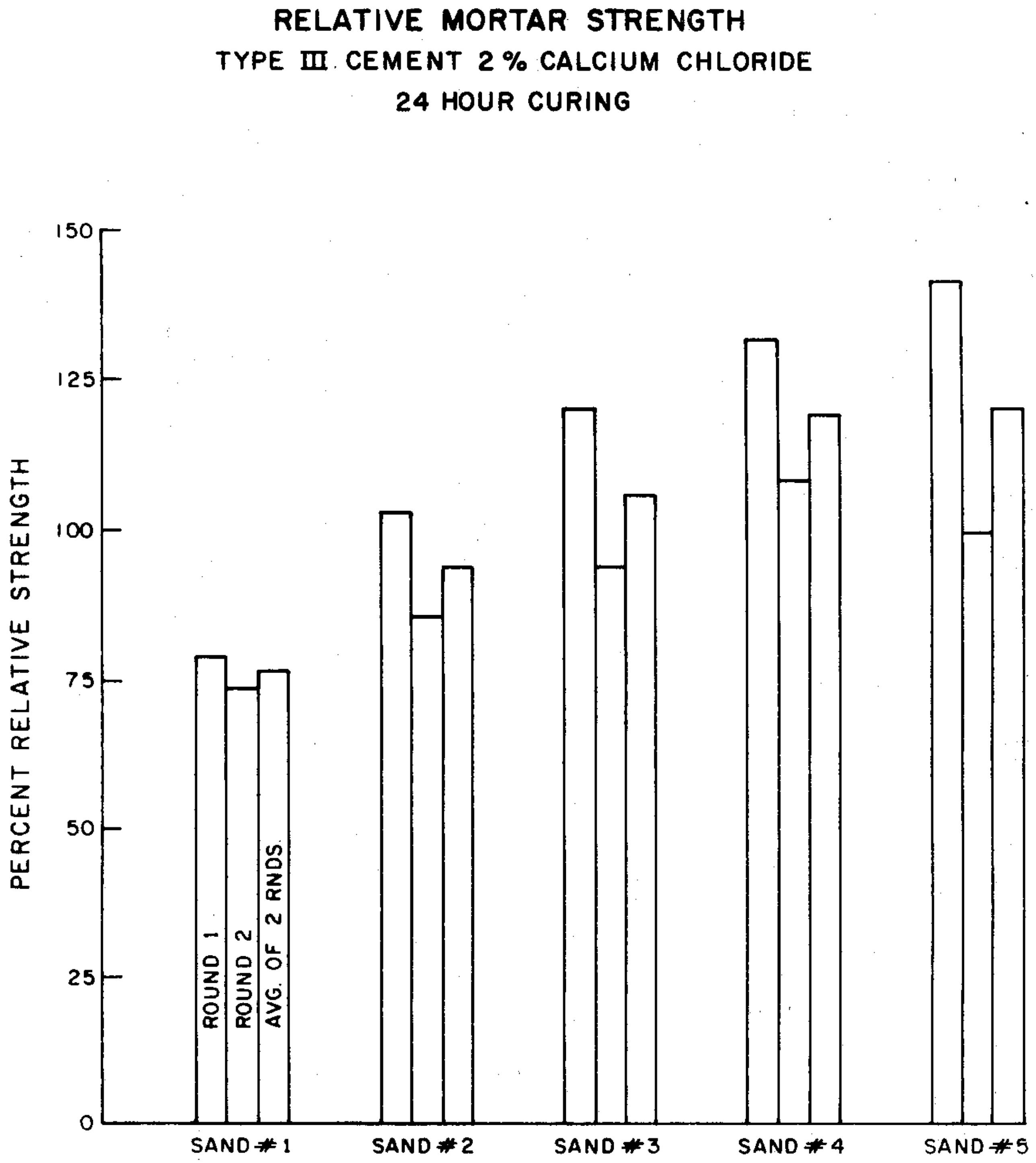
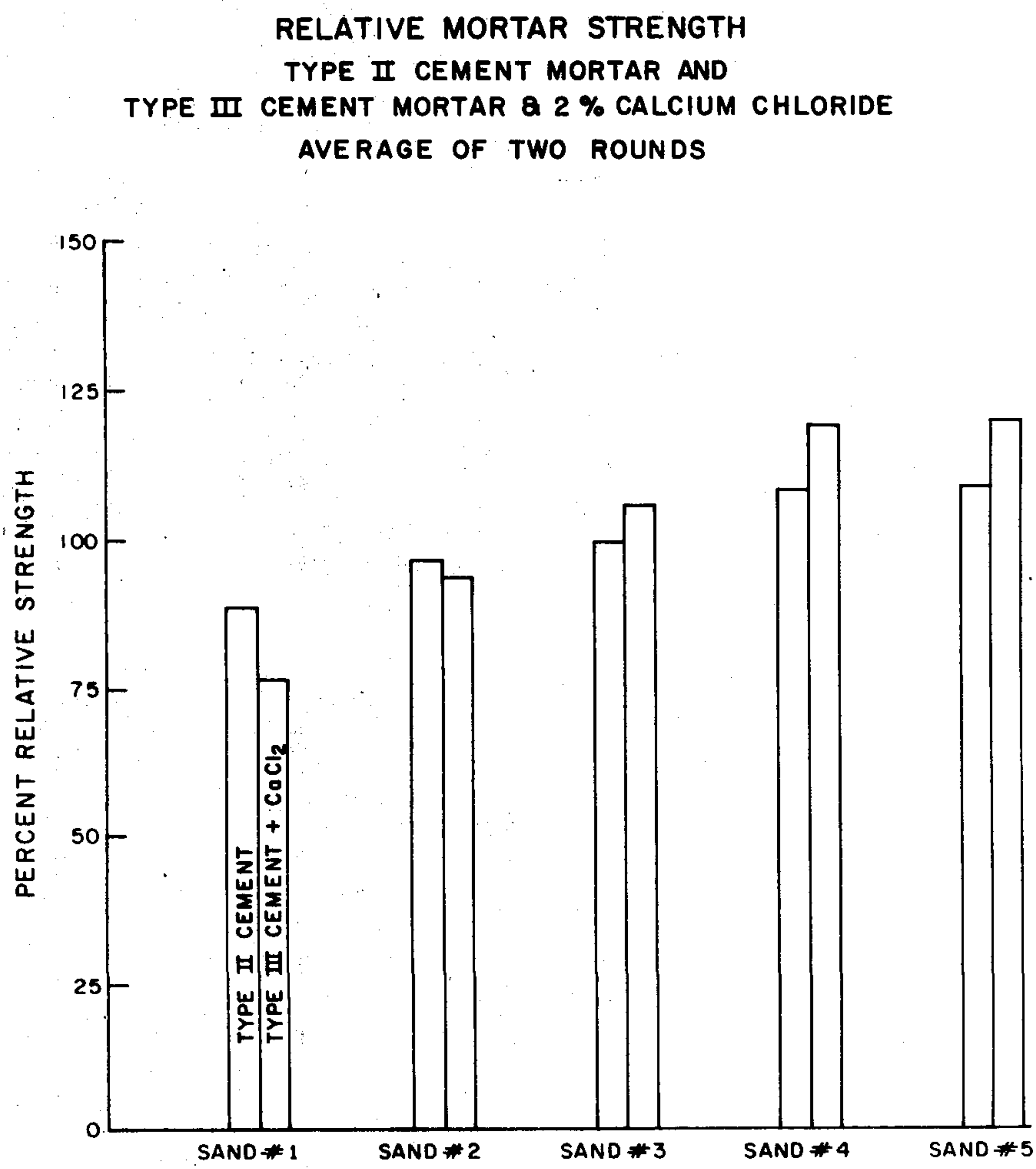

RELATIVE MORTAR STRENGTH
TYPE II CEMENT
7 DAYS CURING
PERCENT RELATIVE STRENGTH
150
125
100
75
50
25
0
ROUND 1
ROUND 2
AVG. OF 2 RNDS.
SAND #1
SAND #2
SAND #3
SAND #4
SAND #5

Figure 3



RELATIVE MORTAR STRENGTH
TYPE III CEMENT 2 % CALCIUM CHLORIDE
24 HOUR CURING
PERCENT RELATIVE STRENGTH
150
125
100
75
50
25
0
ROUND 1
ROUND 2
AVG. OF 2 RNDS.
SAND #1
SAND #2
SAND #3
SAND #4
SAND #5

Figure 4



RELATIVE MORTAR STRENGTH
TYPE II CEMENT MORTAR AND
TYPE III CEMENT MORTAR & 2 % CALCIUM CHLORIDE
AVERAGE OF TWO ROUNDS
PERCENT RELATIVE STRENGTH
150
125
100
75
50
25
0
TYPE II CEMENT
TYPE III CEMENT + CaCl2
SAND #1
SAND #2
SAND #3
SAND #4
SAND #5